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AN OPERATIONS MANUAL FOR THE DIGITAL DATA SYSTEM

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SUMMARY

The Digital Data System (DDS) was designed to provide the researcher with another option for the acquisition and analysis of data. It incorporates the analog-to-digital conversion process into the initial data acquisition stage and stores the data in a digital format. This conversion process is done as part of the acquisition process. Consequently, the data is ready to be down-loaded to the computer and analyzed as soon as the test is completed. This capability permits the researcher to alter test parameters during the course of the experiment based upon the information acquired in a prior portion of the test. The DDS is currently able to simultaneously acquire up to 10 channels of data, each of which can store up to 524,288 data points. Each channel can be down-loaded to the computer in approximately 25 seconds. The number of channels can be increased to at least 100 by inserting additional filter cards and transient data recorders into the system, with no adverse effect on the operation of the system. The input voltage range for the DDS is ± 10 volts, and the input signal can be sampled at rates from 30.5 Hz to 1.0 MHz. More detailed characteristics of each component of the DDS are given in table 1.

Essentially, the system performs four functions; acquisition, storage, analysis, and graphical presentation. The acquisition process is implemented by passing the input signals through filters, and then into transient data recorders. The digitized time series stored in the transient data recorders are then down-loaded onto a Micro-Vax computer for analysis at a convenient time. Software packages are maintained on the Micro-Vax to perform various time and frequency domain analyses, for either single channel functions (computations based on the time history data of a single channel) or cross-channel functions (computations based on the comparison of the time history of one channel with the time history of another channel). Finally, software packages are available to provide convenient data display.

INTRODUCTION

Over the past several years, the emergence of frequency analyzers which incorporate 'hard-wired' FFT algorithms has brought about dramatic improvements in the analysis of time series data. These commercially available 'FFT boxes' have been powerful diagnostic tools for the field or development engineer concerned with the analysis of time fluctuating data. However, the analysis and display inflexibility of these analyzers, together with limited data storage capabilities, severely limit researchers interested in characterizing the dynamic behavior of complex aeroacoustic or vibratory systems. In the past, such efforts have depended upon analog tape recordings whenever large amounts of data were required. This approach has several disadvantages, the chief of which is a slow turn-around rate for data to be converted from analog tapes to digitized results in engineering units. Although this digitization method is well developed, the slow turn-around can constrain the researcher to have to acquire an entire data set without the advantage of being able to look at previous data. Obviously, this can cause delays in the decision-making process during an exploratory-type experiment. Also, in the case of a fixed length experiment, the researcher is often forced to decide on critical parameters in a short period of time without the benefit of 'real-time' analysis of prior data.

Availability of 'FFT boxes' now permits direct data acquisition and immediate analysis. Although the quantity and quality of these devices has significantly increased in recent years, they are still limited in certain respects: (1) the number of input signals is very restricted (typically limited to two simultaneous inputs); (2) the analysis is performed with a limited number of 'hard-wired' statistical functions; and (3) the frequency range is often not high enough to handle data above 100 kHz. If these limitations are not a problem for a given experiment, the 'FFT box' is quite acceptable and might even be preferred. It is becoming increasingly important, however, to be able to acquire more than two input signals simultaneously, over large frequency ranges, and to analyze the responses with various analytical models. In this environment, the inflexibility of 'FFT boxes' becomes readily apparent.

The Digital Data System (DDS) was designed to provide the researcher with increased flexibility for the acquisition and analysis of data. It incorporates the analog-to-digital conversion process into the initial data acquisition stage and stores the data in a digital format. The data is then ready to be down-loaded to the computer and analyzed as soon as the test is completed. This capability permits the researcher to alter test parameters during the course of the experiment based upon the information acquired in a prior portion of the test.

The purpose of this document is four-fold. The first goal is to describe the capabilities of the hardware in sufficient detail to allow the reader to determine whether the DDS is the optimum system for a particular experiment. The second is to describe some of the more significant software which has been developed to provide analyses within a short time of the completion of the data acquisition. These programs are described with the intent of demonstrating typical analysis routines, how the computations are performed, how they are used, and in what format the results are presented. The third goal is to provide the reader with sample runs of the major software routines to demonstrate their convenience and simple usage. Finally, a portion of this document is used to describe software which uses an 'FFT-box' to provide a means of comparison against which the DDS can be checked.

HARDWARE

A schematic of the current DDS configuration is presented in figure 1. Signals from ten transducers are fed through a signal conditioner into separate programmable band-pass filters. The most important function of the filters is to low-pass the signals to prevent aliasing of information above the Nyquist frequency into the analysis bandwidth of interest. The high-pass filter cutoff frequency is also available to increase the flexibility of the system by limiting the DC and low frequency signal contributions. The filtered outputs are then passed to transient data recorders which convert the data from analog to digital format. Each of the transient data recorder channels can be individually set to acquire data at sampling rates from about 30.5 Hz to 1 MHz, as shown in table 1. The filtered outputs are multiplexed into a multimeter and scope to monitor the data on selected channels. All components of the system are controlled interactively by a Micro-Vax computer using IEEE protocol, which allows the digitized data to be stored on hard disks for later analysis. In addition, a spectrum analyzer is often included with the DDS to provide a confidence check to assure that the digitization is being done properly. For field use the system is packaged into two 19" x 24" x 5' racks.

Micro-Vax Computer

The Micro-Vax computer is configured with one internal (71 Mbytes) and two external (275 Mbytes each) hard disk drives. It also contains a 90 Mbyte tape drive which is generally used for back-up storage. For the boundary layer survey experiment presented in the example results of this document, a 4 second run time was estimated. At a sample rate of 125 kHz, a four-second segment of data acquired simultaneously with 10 transducers provides approximately 10 Mbytes of digitized data. Thus, numerous data runs can be stored. An IEEE driver is included to provide interactive control of the devices used in most experiments, and to handle the transfer of data from the devices to the computer. The computer system also includes a laser printer, which provides high quality graphics and text printouts with a minimal amount of turn-around time.

Precision Filters

The filters used in the DDS consist of 12 high-pass and 12 low-pass filters. By pairing each high-pass filter together with a low-pass filter in a serial configuration, the signals are essentially filtered with band-pass filters. Each of the filters is programmable; thus, each input signal can be individually processed. These filters also include pre- and post-gain options, which allow the user to optimize the voltage levels entering and exiting the filters. The selectable pre-gain range of 0 to 40 dB is incorporated to amplify the incoming signal to up to a peak value between -10 and +10 volts, which is the total input range of the Precision Filter system. The post-gain option, with a range of -9.9 to 20.0 dB, is then used to attenuate or amplify the output signal to the desired output level. These filters have a minimum roll-off of about 40 dB per octave. The Precision Filter system also has another convenient feature; it allows separate filters to be grouped together as a single unit. This grouping allows the operator to program more than 1 filter at a time. The instrument also has an overload light on the front panel which lights up whenever any one of the filters is out of the ±10 volts range. When this occurs, the overloaded filter can be located by stepping through the individual filters on the front panel until the 'filter conditions' panel indicates an overload. The usage of the front panel buttons and switches is provided in much greater detail in the operations manual for that particular instrument.

Pacific Instruments Transient Data Recorders

Ten Pacific Instruments Transient Data Recorders (TDR) constitute the core of the DDS. These devices convert analog inputs to digital form and store the results for later down-loading to permanent mass storage. To accomplish this task, each TDR digitizes incoming data at sampling rates ranging from about 30.5 Hz to 1 MHz. Each TDR can store up to 524,288 data points in a normalized format over a range of -10 to +10 volts. The memory section of each TDR is divided into 16 sequential segments that can be individually programmed at different sample rates. In other words, each channel can be configured such that each successive $\frac{1}{16}$ of the data is sampled at a different sampling rate. However, in the present application, the data acquisition routine (GETDAT) is written to operate all 16 segments of each TDR channel at a single sample rate. The default rate is 125 kHz, but an option is included in the routine to select one of 16 available sampling rates from 30.5 Hz to 1 MHz.

Fluke Scanner

In order to perform quick checks on the responses through each of the data channels, the filtered signals are input to a Fluke Scanner which serves as a multiplexer for the system. Thus, the operator can conveniently select the channel of interest to monitor with either a scope, multimeter, or spectrum analyzer. Again, this unit is IEEE-controlled by the computer, so the monitoring process can be entirely operated by the software package.

Tektronix System

A Tektronix System is included in the DDS to enable convenient on-line monitoring of the signals at any stage up to the TDR input. It also allows each portion of the system to be individually tested. This system includes a multimeter, scope, frequency synthesizer, and counter. This system is also controlled using IEEE protocol, thus allowing it to be operated via the Micro-Vax.

SOFTWARE

A number of software routines have been written on the Micro-Vax to acquire and analyze data with the system. These software routines allow the operator to select a number of the important parameters governing hardware operation. The first portion of the following section describes the test routines used to assure that the system is functioning properly. The next section describes the program used to acquire and store the digitized, filtered data. The final section describes software used to perform the available analysis routines, for either single-function or cross-function comparisons. As will be discussed, many of these routines provide plots of the data. Each of these plots is stored in a SAVEPLOT.PLT plot vector file, which can be plotted on the laser printer by typing the command '**DLNS**'.

Hardware Test Routines

All of the hardware test routines are found under the account DUB6:[JONES.HTT]. In order to operate any of these programs, the user must first log onto the Micro-Vax and enter the following command:

SET DEF DUB6:[JONES.HTT]

At this point all of the test routines and most of the acquisition and analysis routines are available.

Precision Filters (TSTPF)

The test program TSTPF performs a quick check of the IEEE control of the filtering system. To operate this program, the user must run the PF command file by typing '@PF'. The PF command file runs the TSTPF program, which interactively sets each channel of the Precision Filter. If completed successfully, the low-pass filters will all be included in the 1A group, while the high-pass filters will be in the 1B group. The low-pass and high-pass filters will be set for cutoff frequencies of 62.5 kHz and 30 Hz, respectively. Also, all of the filters will be set for a pre-gain and post-gain of 0 dB.

Fluke Scanner (TSTFS)

The test program TSTFS was written to allow the operator to interactively select a desired scanner channel. To run this routine, enter the following commands:

(1) **RUN TSTFS**

(2) Select channel of interest; repeat as necessary

(3) Enter **control-z** to end program

If the system is functioning properly, the channel indicator on the front panel of the Fluke Scanner should indicate the selected channel.

Tektronix Multimeter (TSTTM)

The test program TSTTM was written to test the multimeter. It is written on a more basic level than the other test routines, and thus requires a knowledge of the interactive commands for the multimeter, as given in the manual. In order to quickly check to see if the computer is communicating with the multimeter via the IEEE, the following commands can be given:

(1) **RUN TSTTM**

(2) Select the talk mode by entering **0**

(3) **ACV**

(4) **AVE 20**

(5) Enter **control-z** to end program

At this point the multimeter should be set up to read AC voltages using 20 averages per reading.

Data Acquisition

The data acquisition program GETDAT is designed to acquire a sample of data from up to 10 transducers simultaneously. To operate this program the DDS must first be configured as shown in figure 1. The program can then be run with the following commands:

(1) **RUN GETDAT**

(2) Enter the run number and the reference channel number

(3) Select TDR rate code for desired sampling rate from given table

(4) Enter low-pass cutoff frequency [default = 62.5 kHz]

(5) Enter pre-gain amplification for low-pass filters

(6) Enter high-pass cutoff frequency [default = 30 Hz]

(7) Enter post-gain amplification for high-pass filters

(8) Enter **1** to initiate data acquisition by entering <**cr**>, or enter **2** to initiate data acquisition by closure of a limit switch connected to the extender box of the Micro-Vax

(9) Enter <cr> (if **1** was entered at step (8)) or close the limit switch (if **2** was entered) when ready to acquire data

(10) Enter channel (0-9) to be saved in computer memory; repeat as necessary

(11) End program by entering a negative channel number

A sample run of this program is given in Appendix A.

The Precision Filters are interactively set to the selected pre- and post-gain amplifications. The pre-gain amplification, which represents an amplification prior to the filtering process, ranges from 0 to 40 dB, in steps of 10 dB. The post-gain amplification (amplification after the filtering process) ranges from -9.9 to 20.0 dB, in steps of 0.1 dB. This provides a valuable option of pre- and post-conditioning which is useful in monitoring signal amplitudes which must not exceed the range of -10 and +10 volts at the input to the transient data recorders. In the present configuration, the filter section of the DDS is arranged with the low-pass filters ahead of the high-pass filters in the connection sequence. Therefore, the pre-gain amplification is set on the low-pass filters and the post-gain amplification (or attenuation) is set on the high-pass filters. These gain settings are not included in the stored data file, and should thus be recorded separately in a test log. The default filter setting for the GETDAT routine is such that each of the 10 channels is band-pass filtered (low-pass and high-pass filters connected serially) at frequencies between 30 Hz and 62.5 kHz. However, these limits can be easily changed by entering the appropriate values in response to the queries from the program (steps 4 and 6).

The default mode of the acquisition program sets the Pacific Instruments Transient Data Recorders for a sampling rate of 125 kHz. Thus, the default Nyquist frequency is 62.5 kHz. The transient data recorders are set to include all 16 segments for each channel, thus providing 524,288 data points per channel for a 4.2 second time segment. Downloading the data from the TDR to the hard disk requires approximately 24 seconds for each channel. The data will be stored on the DUB6:[MJD6] account using the format 'Rabc.UNC', where 'a' represents the run number, 'b' represents the reference channel number, and 'c' represents the selected data channel number. Of course, it is expected that future tests will not necessarily require frequency information up to 62.5 kHz. Therefore, the option is included (step 3) to select a different sampling rate from the given table.

After using steps 3 through 7 to attain the desired settings for each of the IEEE-controlled devices, the data acquisition is controlled by steps 8 and 9. Typically, a '1' is entered to set the program up to initiate the data acquisition process by entering '<cr>' when the proper test conditions exist. The duration of this acquisition, conversion (analog-to-digital) and storage process is controlled by the chosen sampling rate.

Analysis Procedures

Upon completion of the data acquisition phase (GETDAT), a data file of the form 'Rabc.UNC' is generated on the DUB6:[MJD6] account. Again, 'a', 'b' and 'c' represent the run number, reference channel number, and selected data channel number, respectively. It should be noted that the selected data channel can be the reference channel. The extension 'UNC' is used to indicate that this is a data file which has not been corrected to account for any errors inherent to the acquisition method, either in the frequency response of the transducers or in the DDS hardware. Other software routines, which will not generally be necessary and are thus not discussed in this report, are available to correct for certain of these 'system' errors caused by the usage of transducers past their resonance frequency. These routines modify the data file and generate a new data file with the extension 'RAW', which is used to indicate that this data file contains a representation of the measured physical phenomenon without any system contaminations.

Single-Function Analyses (SNAP)

The program SNAP is designed to perform four commonly used single-function analyses. It is used to read either the data files output from the GETDAT routine (Rabc.UNC) or the corrected data files (Rabc.RAW). A sample run of SNAP is given in Appendix B. The first calculation of this routine is a statistical stationarity estimate. The procedure is to divide the 524,288 point data set into 128 blocks of 4096 points each. The next step is to perform a 'RUNS' test on the data, as explained in references 1 and 2. This 'RUNS' test provides the researcher with an indication of the stationarity of the acquired data. This test is described in more detail in Appendix C. The results of this test can then be compared with the table given in reference 3 to determine the stationarity of the data.

The next step in the SNAP routine is a comparison of the data probability distribution function with that of a Gaussian distribution. Essentially, the amplitude range of the data is divided into 100 bins (each bin represents $\frac{1}{100}$ of the amplitude range), and each data point is placed into a bin according to amplitude. The output of this analysis, in bin amplitude versus number of points in each amplitude bin, provides a probability distribution function plot. The mean and variance of the entire data set are then used to compute the Gaussian (normal) distribution function for comparison purposes. If the two distributions are reasonably matched (qualitatively, by eye), the normality of the data is considered to be within acceptable limits.

The remainder of the program computes several statistical functions of greatest interest to the researcher. This section computes the autocorrelation and power spectral density of each block of data. It then averages these results over the entire number of blocks to allow the operator to conveniently plot either separate (individual block of data) or average (of all 128 blocks) autocorrelations and power spectral densities. A few of these plots are included in the sample run given in Appendix B. The actual calculation of these functions is done with routines found in the IMSL library in the SYS$LIBRARY account (link using SYS$LIBRARY:IMSLIBS/LIB). The FTAUTO subroutine is used to compute the mean, variance, and autocorrelation for each block, while the FFTRC routine is used to compute the power spectral density. Each of these routines is described in more detail in Appendix D.

Cross-Function Analyses (XCC and PXC)

The program XCC is written to compute and plot cross-correlations, coherences and transfer functions between time histories acquired using two different transducers. Again, the input time history data files are assumed to come from the DUB6:[MJD6] account with the form 'Rabc.UNC' or 'Rabc.RAW', as described in previous sections. In addition to the cross-function plots, a file of the type 'Xa.XCC', where 'a' represents the run number, is used to store the cross-correlations for each channel of a particular run. This file can then be input to the PXC program to provide a combined plot of all of the cross-correlations (one curve per channel). The equations used to compute all of these cross-functions are described in Appendix E. Also included in Appendix E is a sample run of XCC.

Quick Look Routines

Monitored Results (MON1)

The program MON1 was written to plot the monitored data, for each of the 10 channels, saved by the GETDAT data acquisition program. This program is run with the following steps:

(1) **RUN MON1**

(2) Enter run number, reference channel number

(3) For each comparison channel available, enter the time increment at which to plot the results

The program will proceed to read files of the form 'Rabc.UNC' from the DUB6:[MJD6] account, where 'a' and 'b' represent the selected run number and reference channel, and 'c' represents the available comparison channels. First, a search is conducted to determine which comparison channels were recorded. Next, each available comparison channel data file is read and stored in an internal array. Finally, the AC voltage is plotted versus time for all available channels, each at their respective time increment, on a single figure.

Digitized Results (TDA)

The program TDA was written to quickly view digitized data acquired with the Pacific Instruments Transient Data Recorders. This routine allows the operator to conveniently print portions of any segment of an output file created by the GETDAT program of the form 'Rabc.UNC', where 'a', 'b', and 'c' represent the run number, reference channel number, and measurement channel number, respectively. It also provides the option of looking at the data after it has been "corrected" (extension changed to RAW). To run this routine, use the following commands:

(1) **RUN TDA**

(2) Enter run number, reference channel number, data channel number

(3) Enter **0** if file extension is '**RAW**' or **1** if file extension is '**UNC**'

The program will output a short display describing the settings which were used in the TDR during the test. These settings are displayed in a coded format which can only be deciphered by reading the manual for the Pacific Instruments Transient Data Recorders. The program will then step through each of the 16 segments of data acquired with the TDR channel selected (DATA CHANNEL number), allowing the operator to decide how many data points (time, voltage), if any, of each segment are to be printed to the screen.

COMPARISON PROCEDURE USING NICOLET ANALYZER

The Nicolet Analyzer is capable of determining autocorrelations, cross-correlations, coherences, transfer functions, power spectral densities, and probability distribution functions. It is frequently used to provide another quick check on the accuracy of the analyses procedures. Therefore, although it is not an integral part of the Digital Data System, the following section will describe its usage.

Data Acquisition with Tandy Computer

The Nicolet Analyzer is presently configured to be controlled interactively with a Tandy computer using an RS-232 line. After booting the Tandy computer and connecting from the back of the Tandy to the RS-232 port on the Nicolet Analyzer, the following steps can be taken to run the analyzer and to store the results on disk.

(1) Place disk with NIC program in drive B

(2) Switch control to drive B by typing **B:**

(3) Type **NIC** to run data acquisition program

(4) Enter data file name

(5) Set up front panel of analyzer as desired and skip options to interactively control the front panel

(6) Enter number of averages desired

(7) Enter carriage return to initiate averaging

The analyzer should then acquire the desired number of averages and store the results on drive B under the selected data file name. The program then returns to step 5 and allows the operator to perform another measurement. Each successive measurement is stored in the data file as a new data set until the operator terminates the program. The data file is then ready for transfer to the Micro-Vax, where the results can be either printed or plotted for comparison purposes.

Data Transfer To Micro-Vax

The following steps describe the method for transferring files from drive B of the Tandy, through the PDP 11/73, to the Micro-Vax.

(1) Type **A:** to switch control to A disk

(2) Copy file to drive A by typing **COPY B:file.ext A:**

(3) Replace disk in drive B with disk which contains KERMIT routine

(4) Type **B:** to switch control to B disk

(5) Disconnect RS-232 cable from analyzer and connect RS-232 cable from the PDP 11/73 computer to the back of the Tandy

(6) Type **KERMIT**

(7) Type **CONNECT**

(8) Log into the PDP 11/73 and type **.KER**

(9) Type **SERVER**; then enter **control-C** followed by]

(10) Type **SEND A:file.ext** to pass file to PDP 11/73

(11) Log onto Micro-Vax and enter **SET DEF DUB6:[JONES.NIC]**

(12) Type **COPY B1287::DL1:[your uic]file.ext** []

At this point the data file should be resident in the DUB6:[JONES.NIC] account, which is where the output routines for the Nicolet Analyzer reside.

Output Routines (NPLT and NPRT)

Two output routines, NPLT and NPRT, are available on the DUB6:[JONES.NIC] sub-directory. These two routines allow the operator to either plot or print all or portions of the data acquired with the NIC program on the Tandy computer. To run either of these routines, type '@NIC' to engage the NIC command file. The command file will then offer the selection of NPRT (option 1) or NPLT (option 2). If the operator chooses to run NPRT, the following steps are taken:

(1) Enter file name

(2) Enter set number (0 for all); easiest to just enter 0

(3) Enter x-axis range of interest (low, high values); enter 0,0 to print out entire data set

(4) Choose to either return to step 2 or quit

Similarly, if the operator chooses to run NPLT, the following steps are taken:

(1) Enter file name

(2) Enter set number (0 for all); easiest to just enter 0

(3) Enter carriage return to clear screen after each plot

(4) Determine whether or not to send output to Laser printer

APPENDIX A: Sample Run of GETDAT

The following is a sample run of the GETDAT data acquisition routine:

```
//SET DEF DUB6:[JONES.HTT]
//RUN GETDAT
Enter RUN #, REF CHAN # :100,0

        SAMPLE RATE TABLE
   Rate Code          Sample Rate
      15                1 MHz
      14                500 kHz
      ...               ...
      12                125 kHz
      ...               ...
       2                122.1 Hz
       1                61 Hz
       0                30.5 Hz
   Select Rate Code for desired Sampling Rate : 12
ENTER LOW-PASS CUTOFF FREQUENCY (0.001 TO 204.7 kHz)
[0 - USE DEFAULT OF 62.5 kHz] : 0
```

```
ENTER PRE-GAIN FOR LOW-PASS PRECISION FILTERS
[0 THRU 40, STEPS OF 10 dB] : 10
ENTER HIGH-PASS CUTOFF FREQUENCY (INTEGER, 1 TO 102300 Hz)
[0 = USE DEFAULT OF 30 Hz] : 0
ENTER POST-GAIN FOR HIGH-PASS PRECISION FILTERS
[-9.9 THRU 20.0, STEPS OF 0.1 dB] : -4.4
INITIATE TDRS FROM KEYBOARD (1) OR BACK PLANE (2)? : 1
<cr>
ENTER CHANNEL TO OUTPUT TO FILE (0-9) [<0 TO QUIT] : 3
CREATING FILE DUB6:[MJD6]R1000003.UNC
RUN     100: CHAN     3
524288 PTS : DEL T,(ms) = 8.0000004E-03
SEGMENT   1
SEGMENT   2
...
SEGMENT   15
SEGMENT   16
ENTER CHANNEL TO OUTPUT TO FILE (0-9) [<0 TO QUIT] : -1
FORTRAN STOP
```

In this sample run, a run number of 100 and a reference channel of 0 were chosen. The sample rate of 125 kHz was then selected by entering a rate code of 12. The default low-pass cutoff frequency of 62.5 kHz was chosen, together with a pre-gain amplification of 10 dB. The high-pass cutoff frequency and post-gain amplifications were then set at 30 Hz and -4.4 dB, respectively. A '1' was entered to allow the transient data recorders to be started by entering a '<cr>', then a '<cr>' was entered to initiate the data acquisition. Channel 3 was selected as the output data channel, thus saving the data from TDR channel 3 in the data file R1000003.UNC. As shown in the display, a total of 524,288 points was saved at a time increment of 8 μsec. After this file was saved, no more channels were of interest. Thus, a '-1' was entered to terminate the program.

APPENDIX B: Sample Run of SNAP

This appendix contains a sample run of the SNAP analysis routine.

```
#SET DEF DUB6:[JONES.HTT]
#RUN SNAP
ENTER RUN #, REF CHAN #, MEAS CHAN # [< 0 TO QUIT] : 24,1,4
```

```
IS DATA CORRECTED BY TRANSFER FUNCTION? (0 = Y: .RAW, 1 = N: .UNC) : 0
SEARCHING FOR FILE --- DUB6:[MJD6]R0240104.RAW
READING DATA FROM FILE DUB6:[MJD6]R0240104.RAW
SEGMENT COUNTER OF 16
1 2 ... 15 16
ENTER 1ST PT OF 2500 FOR TIME PLOT (<=0 TO SKIP) : 1
HIT <cr> TO CONTINUE
ENTER 1ST PT OF 2500 FOR TIME PLOT (<=0 TO SKIP) : 0
COMPUTING TOTAL MEAN AND VARIANCE
SELECT AUTOCORRELATION (A-C) OPTION:
N = 0 : PLOT AVE A-C OF ALL BLOCKS
N < 0 : SKIP A-C SECTION
N > 0 : PLOT A-C FOR BLOCKS N --> N+4, PLUS AVE A-C OF ALL BLOCKS
ENTER N : 0
ENTER # DELTA t's AT WHICH TO COMPUTE A-C's (< 2001) : 100
BLOCK COUNTER OF 128
1 2 ... 19 20
...
121 122 ... 127 128
    HIT <cr> TO CONTINUE
SELECT PSD OPTION:
N = 0 : PLOT AVE PSD OF ALL BLOCKS
N < 0 : SKIP PSD SECTION
N > 0 : PLOT PSD FOR BLOCKS N --> N+4, PLUS AVE PSD OF ALL BLOCKS
ENTER N : 4
BLOCK COUNTER OF 128
1 2 3 4
    HIT <cr> TO CONTINUE
5
    HIT <cr> TO CONTINUE
6
    HIT <cr> TO CONTINUE
7
    HIT <cr> TO CONTINUE
8
```

```
    HIT <cr> TO CONTINUE
9 10 ... 19 20
...
121 122 ... 127 128
ENTER CALIB dB [SPL= 10*ALOG10{ FFT∧2} +CALDB] 54
    HIT <cr> TO CONTINUE
    HIT <cr> TO CONTINUE
TOTAL MEAN = 0.56915E-02 TOTAL VAR = 0.15535E+01

  BLOCK              MEAN            VAR
    1            -0.63382E-02     0.15595E+01
    2             0.70398E-02     0.19630E+01
   ...              ...             ...
   127           -0.48928E-02     0.14594E+01
   128           -0.70851E-02     0.22733E+01

    TOT IN PDF = 0.10000E+01 TOT IN GS = 0.50570E+01
# RUNS IN MEAN = 85: # RUNS IN VARIANCE = 57
FORTRAN STOP
```

In this sample run of SNAP, run number 24 was analyzed for a reference channel of 1 and a measurement channel of 4. These data were taken from the file R0240104.RAW, found on the DUB6:[MJD6] directory. After reading in the data from the data file, a '1' was entered to plot the first 2500 time steps from the input time history (fig 2). The program was then set to compute the autocorrelation at 100 time lags plus the zero time lag. In other words, the autocorrelation function was computed at time lags of 0 to 0.8 msec, in steps of 8 μsec. For this sample case, only the average autocorrelation was plotted (fig 3). By entering a number from 1 to 128, a set of 5 autocorrelation plots (one for each of the blocks, beginning with the entered block number) could have been displayed. Also, by entering a negative number, the option to compute autocorrelations could have been skipped completely.

The next portion of the program was designed to compute the power spectral density of each block and, hence, the average power spectral density of the entire data set. Five blocks, starting at block 4, were chosen for plotting. Thus, as shown in figure 4, the power spectral density of the time history in each of these blocks was plotted (only block 4 is shown). This computation was done for each of the 128 blocks, and the average power spectral density was then plotted, as shown in figure 5. A calibration factor of 54 dB was used, to show the calibrated results in the plot. Typically, a calibration data set which uses a known level at a given frequency is acquired with GETDAT. This calibration run is then analyzed with SNAP with a calibration factor of 0 dB. The level at the given frequency is then compared with the known source level, and the difference is used as the calibration factor for future analyses. The probability distribution function of the entire time history was then plotted versus the calculated Gaussian distribution, as shown in figure 6, to demonstrate the normality of the data set. Next, the total and block values for the mean and variance were printed for comparison purposes. Finally, the number of runs, based on either the means or the variances, was printed for a stationarity check.

APPENDIX C: Stationarity Test Description

As described in references 1 through 3, the stationarity of a time history is determined with a 'RUNS' test. To conduct a 'RUNS' test, the entire time history is divided into NBL blocks. The mean of each block of data is compared with the mean of the entire data set. Each block of data is then assigned a value of '-1' if the block mean is less than the total mean, or '+1' if the block mean is greater than or equal to the total mean. A RUN consists of a string of consecutive blocks with like value (e.g. 4 consecutive blocks of data with mean values less than the total mean represent 1 RUN). The total number of RUNS is then compared with values in the table given in reference 3 to determine the degree of data stationarity. This 'RUNS' test can also be conducted on variances instead of means, and both are included in the SNAP routine.

APPENDIX D: Description of FTAUTO and FFTRC Routines

The FTAUTO routine found in the IMSL library is used in the analyses routines to compute means, variances, and autocorrelations. The mean is computed using the equation

$$MEAN = \frac{1}{LW} \sum_{i=1}^{LW} W_i$$

where LW is the length of the time series and W_i represents a single element of that series. The variance is then computed with the relation

$$VAR = \frac{1}{LW} \sum_{i=1}^{LW} (W_i - MEAN)^2$$

Finally, the autocorrelation is computed by the equation

$$AC_j = \frac{1}{(LW)(VAR)} \sum_{i=1}^{LW-j} (W_i - MEAN)(W_{i+j} - MEAN)$$

for $j = 1$ to K, where K represents the number of time lags at which the autocorrelation, AC_i, is to be computed.

The FFTRC routine, also in the IMSL library, is used to compute the Fourier Transform, X, of the input time history, A, with the following formula

$$X_{k+1} = \sum_{j=0}^{N-1} A_{j+1} e^{(2\pi jk)i/N}$$

for $k = 0,1...N/2$ and $\pi = 3.14159$. The power spectral density is then computed by multiplying each component of X with its complex conjugate and scaling with the factor $2\pi/BT$, where BT is the time length of the data block. This computation results in a magnitude for each frequency which can be converted to a relative dB level by taking the logarithm (base-10) and multiplying by 10.

APPENDIX E: Cross-Function Computation and Output

This section describes the method used by the XCC program to compute the cross-correlation, coherence, and transfer function between two selected time histories. For clarity, it also includes a sample run of the XCC routine. First, the computation of the cross-correlation between two signals is performed with the following code:

```
DO I=1,NTS
 RXY(I)=0.0
 DO J=1,NPT-I+1
 RXY(I)=RXY(I)+(X(J)-TMX)*(Y(J+I-1)-TMY)
 END DO
 RXY(I)=RXY(I)/FLOAT(NPT)/SDX/SDY
END DO
```

In this code, RXY(I) represents the cross-correlation between the X and Y time histories at the I'th point. NPT and NTS represent the number of points to be used in the computation (selected by operator) and the number of time lags at which to perform the computation. Also, the means (TMX and TMY) and variances (SDX and SDY) of X and Y are used in the calculations.

The coherence between the two signals is computed with the following procedure:

(1) Compute average power spectral density of X signal

(2) Compute average power spectral density of Y signal

(3) Compute average cross-spectral density by multiplying FFT of Y by the conjugate of the FFT of X and averaging over the number of blocks

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(4) Take the complex absolute value of the result (at each frequency)

(5) Coherence (at a given freqency) = Result of step 4 divided by results of step 1 and step 2

Finally, the transfer function between the signals X and Y is computed by dividing the FFT of Y by the FFT of X at each frequency. This is done for each block of data, and then averaged for an overall transfer function description.

The remainder of this section describes a sample run of the XCC program.

```
//SET DEF DUB6:[JONES.HTT]
//RUN XCC
IT IS ASSUMED THAT THE DATA FILES TO BE USED WILL
CONTAIN DATA OBTAINED AT THE SAME DELTA T INCREMENT
SELECT ::: X-CORR AND COH:TF (0); X-CORR (1); COH:TF (2) : 0
ENTER RUN NUMBER, REF CHAN, COMP CHAN : 24,1,4
IS DATA CORRECTED BY TF (0=Y: .RAW, 1=N: .UNC) : 0
READING FROM FILE DUB6:[MJD6]R0240100.RAW
SEGMENT COUNTER OF 16
1 2 3 ... 14 15 16
READING FROM FILE DUB6:[MJD6]R0240104.RAW
SEGMENT COUNTER OF 16
1 2 3 ... 14 15 16
// PTS AVAILABLE FOR X-CORR IS 524288.
ENTER // PTS TO BE USED (0 TO USE ALL AVAILABLE) : 20000
COMPUTING TOTAL MEANS AND VARIANCES OF X AND Y
MEAN OF X(t) IS 0.32990601E-01 : MEAN OF Y(t) IS 0.42732391E-02
VARIANCE OF X(t) IS 0.96799862E+00 : VARIANCE OF Y(t) IS 0.17205340E+01
ENTER MAX TAL // [e.g. 5 for 5*DT] (MAX = 499) : 50
TAL COUNTER OF 51
1 2 3 ... 18 19 20
21 22 23 ... 38 39 40
41 42 43 ... 49 50 51
    HIT <cr> TO CONTINUE
COMPUTING COHERENCE AND TRANSFER FUNCTION
BLOCK COUNTER OF 128
1 2 3 ... 18 19 20
```

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```
...
121 122 123 ... 126 127 128
    HIT <cr> TO CONTINUE
    HIT <cr> TO CONTINUE
ENTER NEXT COMP CHAN [ < 0 TO QUIT] : -1
FORTRAN STOP
```

In this sample case, run number 24 was analyzed and compared with the reference channel signal (channel 1). The first choice was to compute all three functions. As shown, the operator could have chosen to plot only the cross-correlation or the combination of the coherence and the transfer function. The next input was the information describing which data set should be used (channel 4 compared with reference channel 1). A '0' was entered to indicate that the data files had an extension 'RAW', as described in the previous sections. Data was then read from the reference channel data (R0240101.RAW) and the measurement channel (R0240104.RAW). The next option was to determine the number of points (20000) to be used in the computation of the cross-correlation function. After computing (and printing to the screen) the total mean and variance of each of the input signals, a query was given to determine the number of time lags at which the cross-correlation should be computed (50 for this test run). The program then proceeded to compute and plot the cross-correlation (fig 7), coherence (fig 8), and transfer function (fig 9), with a carriage return input entered to clear the screen after each one. Finally, an option was included to allow the choice of another measurement channel to compare to the reference channel. In this case, a '-1' was entered to terminate the sample run.

REFERENCES

1. Bendat, J.S. and Piersol, A.G.; RANDOM DATA: ANALYSIS AND MEASUREMENT PROCEDURES, Section 7.4, pp. 233-237, WILEY-INTERSCIENCE, 1971.
2. Hardin, J.C.; INTRODUCTION TO TIME SERIES ANALYSIS, NASA Reference Publication 1145, Section 6.5, pp. 55,56, March, 1986.
3. Bendat, J.S. and Piersol, A.G.; RANDOM DATA: ANALYSIS AND MEASUREMENT PROCEDURES, Table A.6, p. 396, WILEY-INTERSCIENCE, 1971.

TABLE 1. SPECIFICATIONS FOR DIGITAL DATA SYSTEM COMPONENTS

A. PRECISION FILTERS

LOW-PASS FILTERS	LOW	HIGH	RESOLUTION
INPUT VOLTAGE	-10 V	10 V	
OUTPUT VOLTAGE	-10 V	10 V	
PRE-GAIN AMPLIFICATION	0 dB	40 dB	10 dB
POST-GAIN AMPLIFICATION	-9.9 dB	20 dB	0.1 dB
CUT-OFF FREQUENCY	1 Hz	204.7 kHz	1 Hz

HIGH-PASS FILTERS	LOW	HIGH	RESOLUTION
INPUT VOLTAGE	-10 V	10 V	
OUTPUT VOLTAGE	-10 V	10 V	
PRE-GAIN AMPLIFICATION	0 dB	40 dB	10 dB
POST-GAIN AMPLIFICATION	-9.9 dB	20 dB	0.1 dB
CUT-OFF FREQUENCY	1 Hz	102.3 kHz	1 Hz

ROLL-OFF CHARACTERISTICS AT LEAST 40 dB/OCTAVE

B. TRANSIENT DATA RECORDERS

INPUT VOLTAGE	-9.9 V	10 V	4.86 mV
OUTPUT VOLTAGE	-9.9 V	10 V	4.86 mV
STORAGE CAPACITY (# OF DATA POINTS)	0	524288	1

SAMPLE RATES === $2^{(i-15)} * 10^{6}$, for i=0 to 15, in Hz

C. MICRO-VAX STORAGE

ONE INTERNAL HARD DISK	71 MEGA-BYTES
TWO EXTERNAL HARD DISKS	275 MEGA-BYTES (EACH)
ONE TAPE DRIVE (TK50)	71 MEGA-BYTES

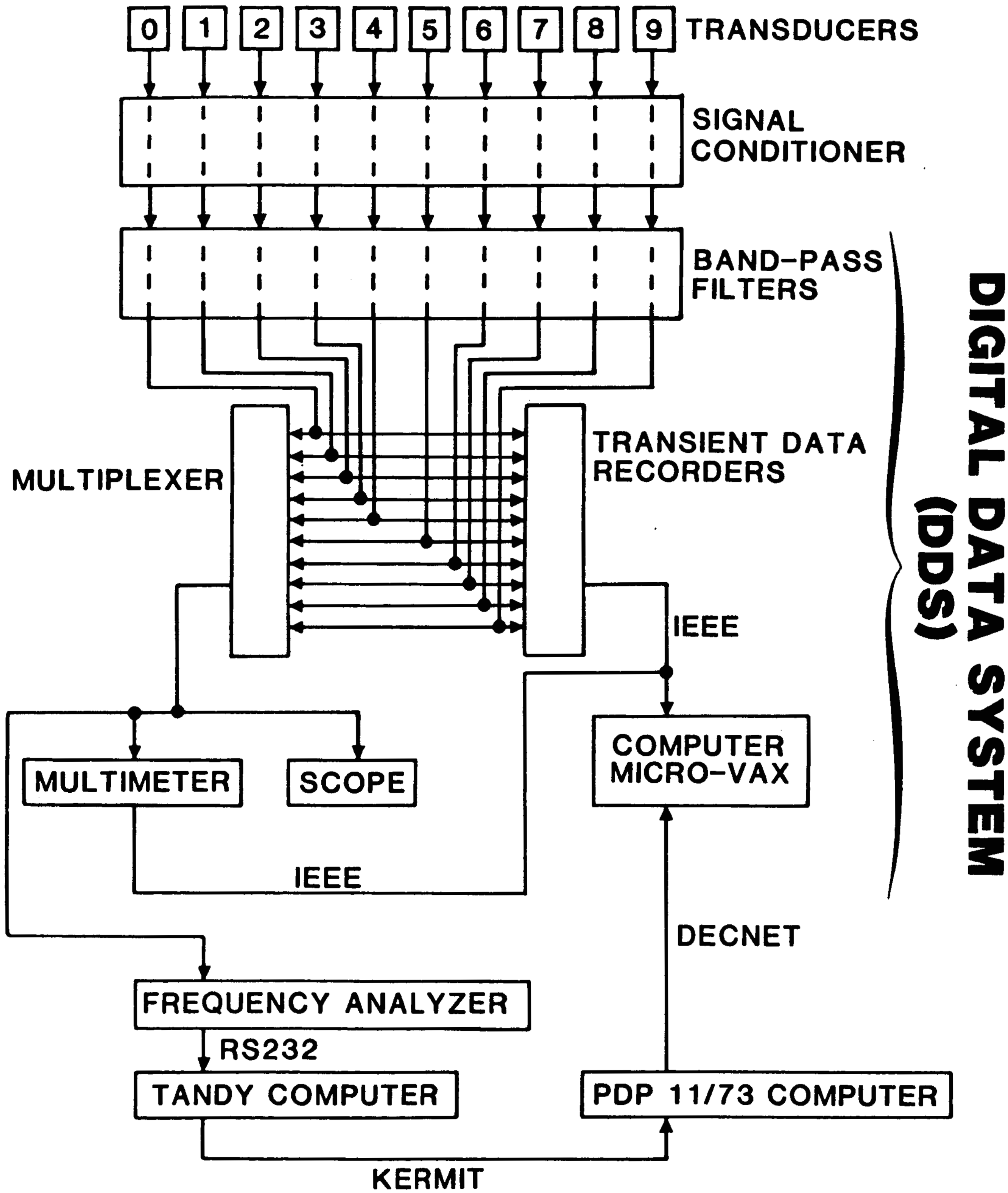

Figure 1.- Instrumentation schematic.

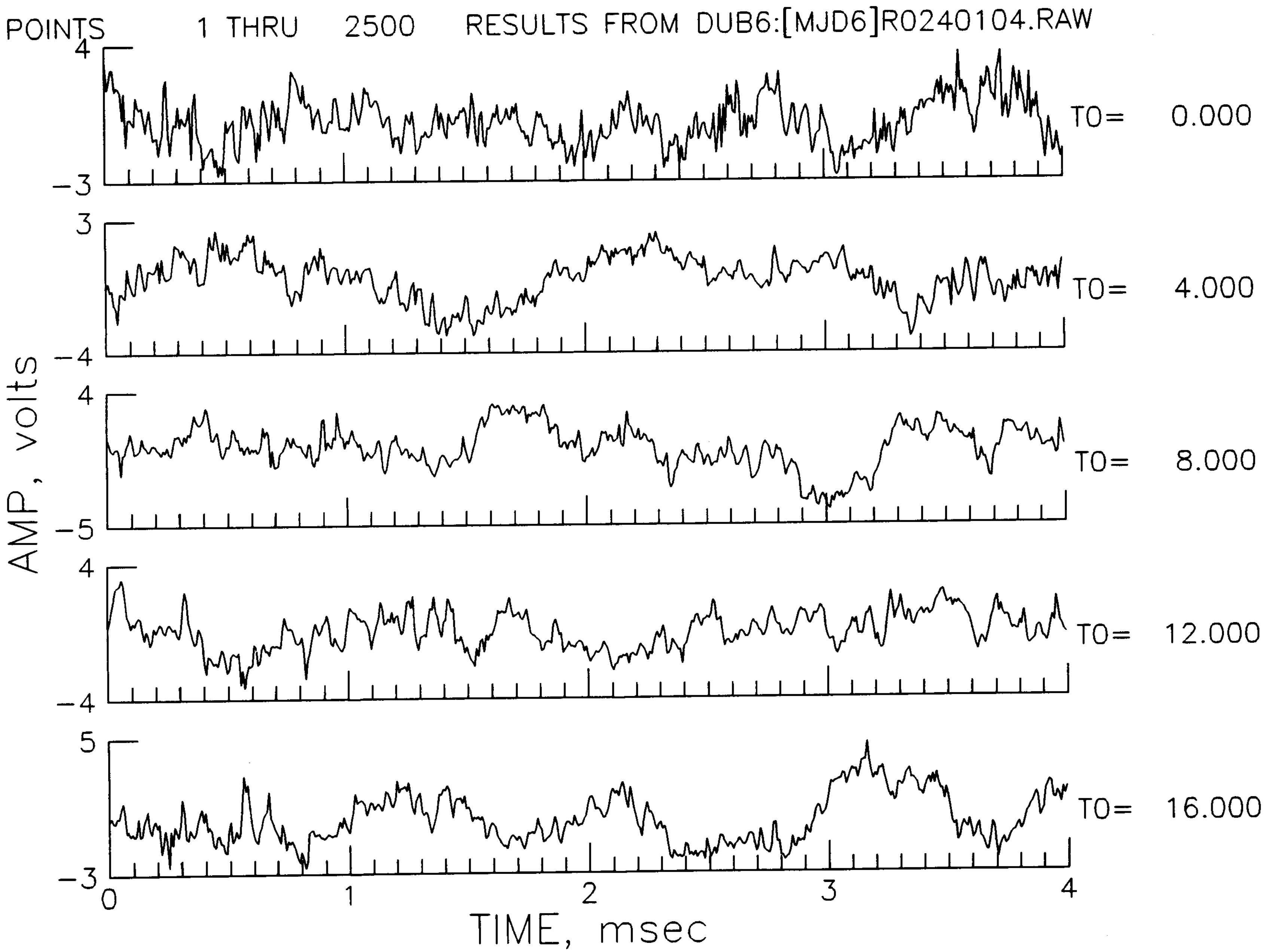

Figure 2.- Input time history.

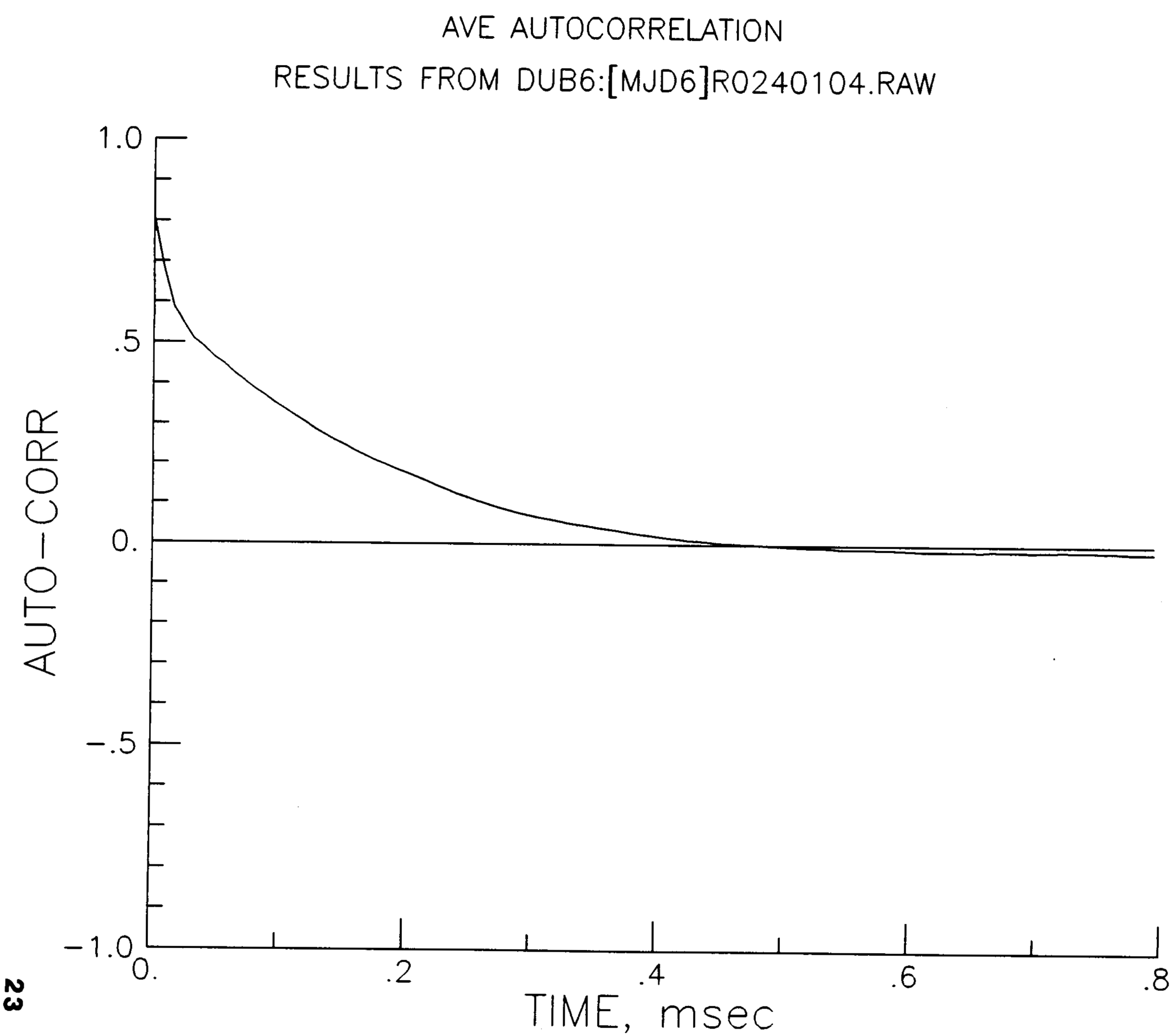

Figure 3.- Average autocorrelation.

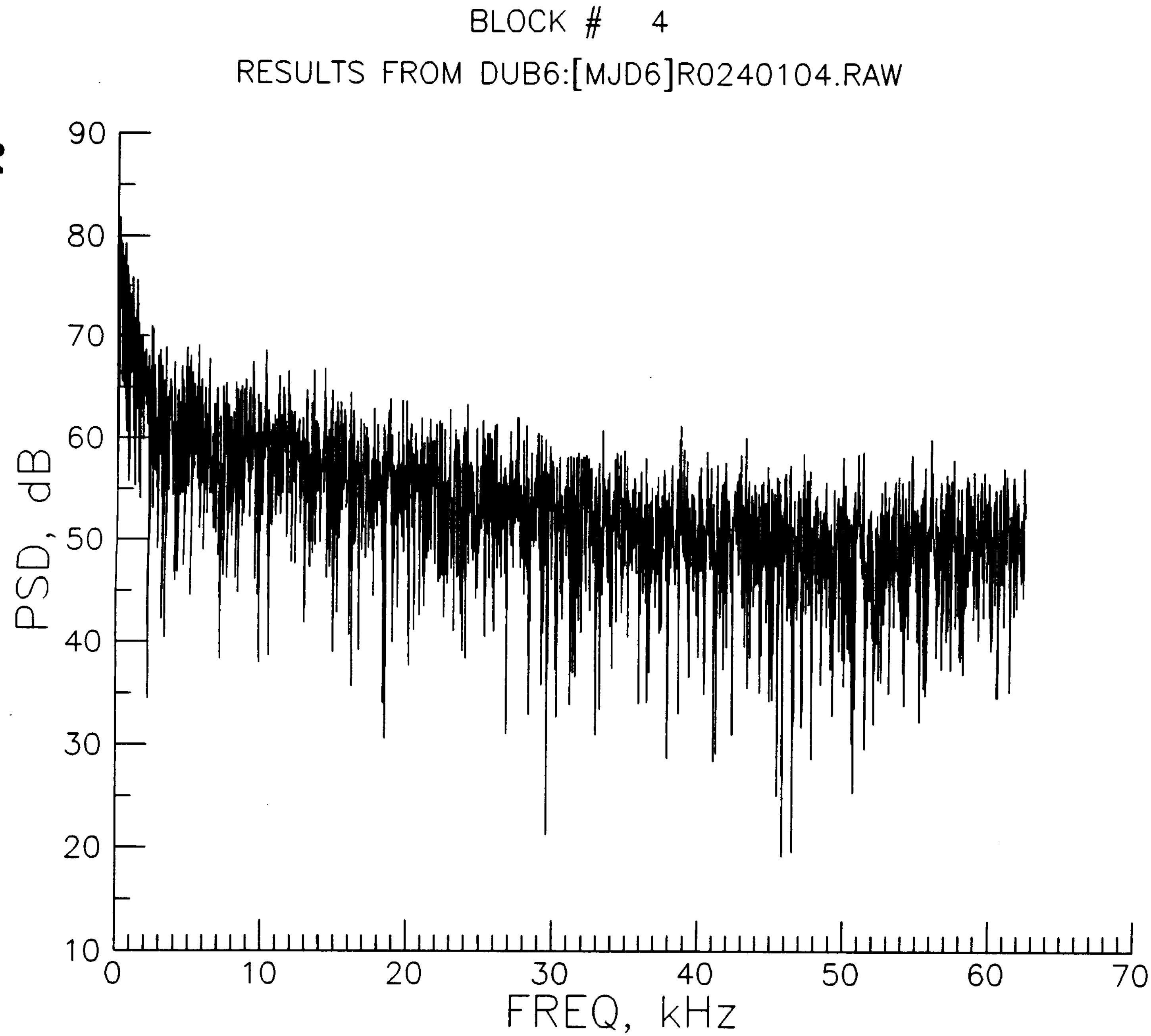

Figure 4.- Power spectral density of fourth block of data.

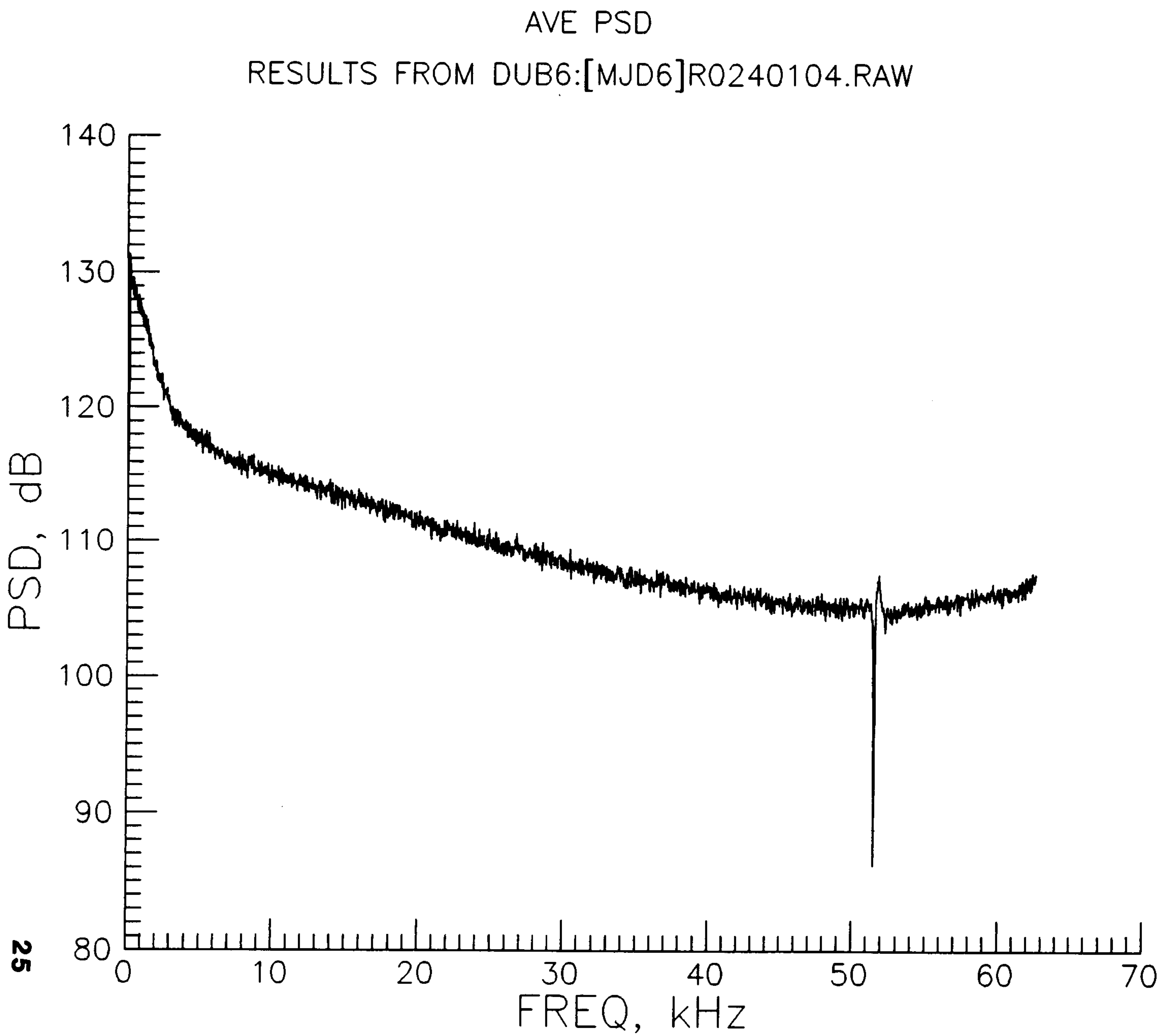

Figure 5.- Average power spectral density.

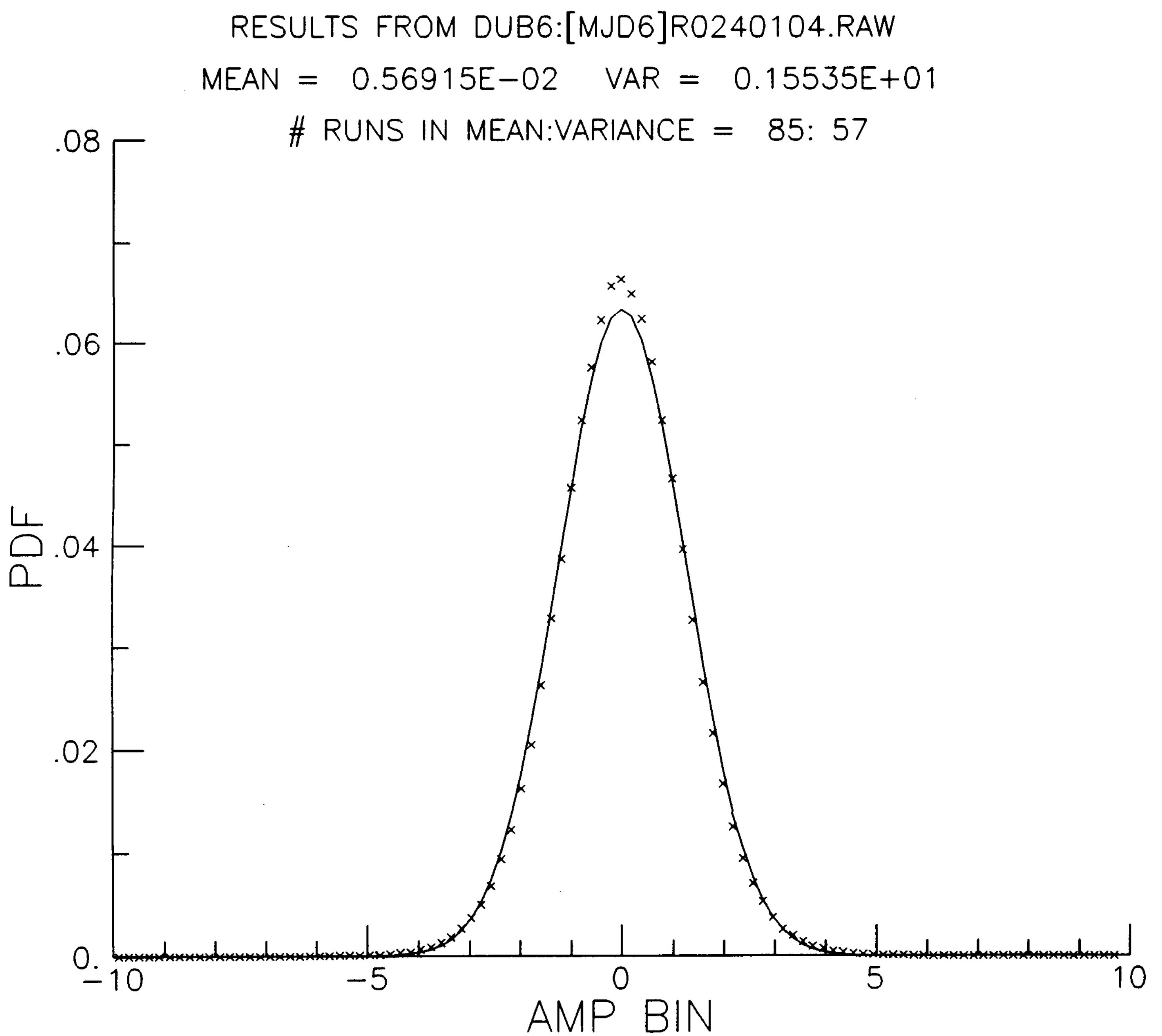

Figure 6.- Probability distribution function.

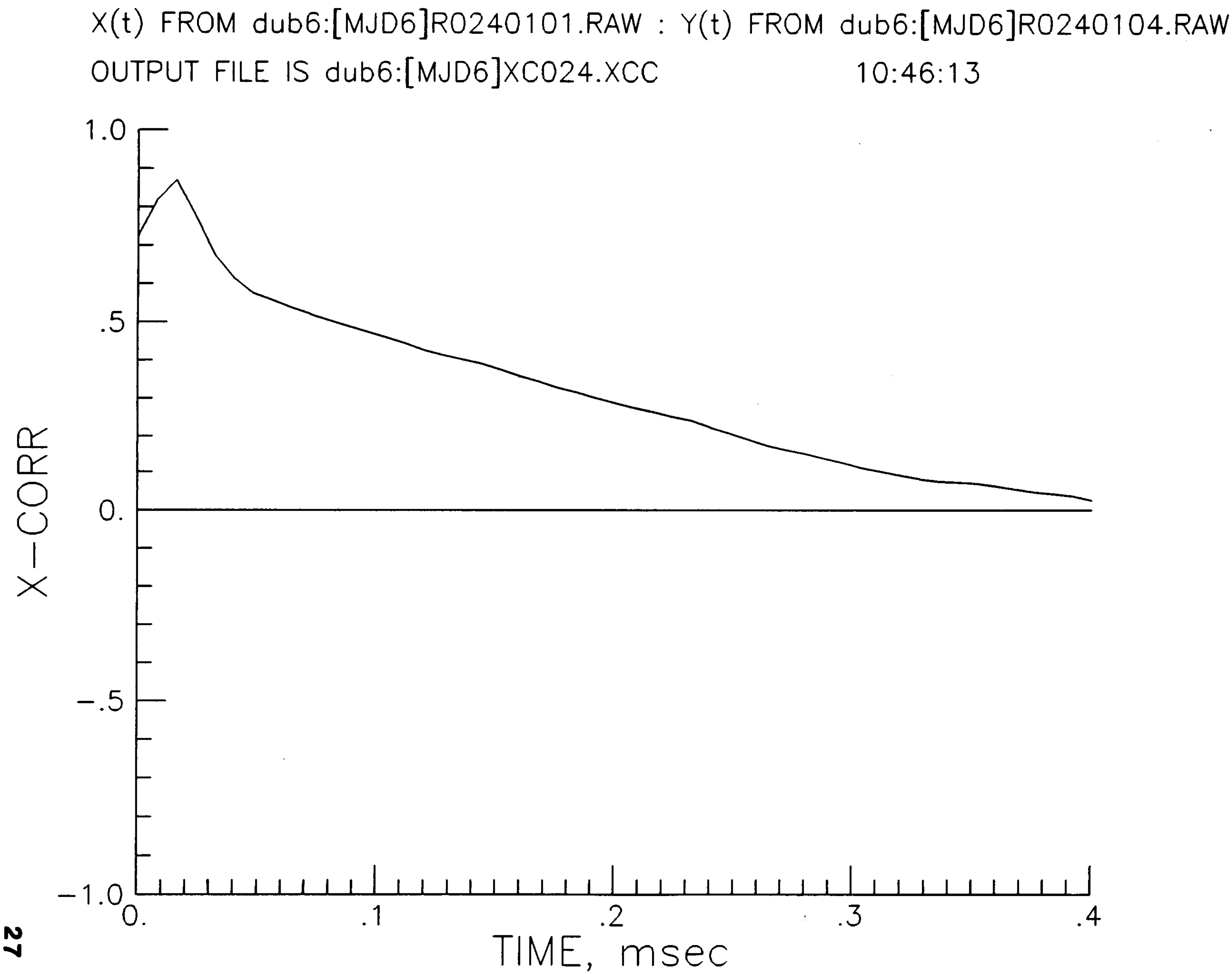

Figure 7.- Cross-correlation.

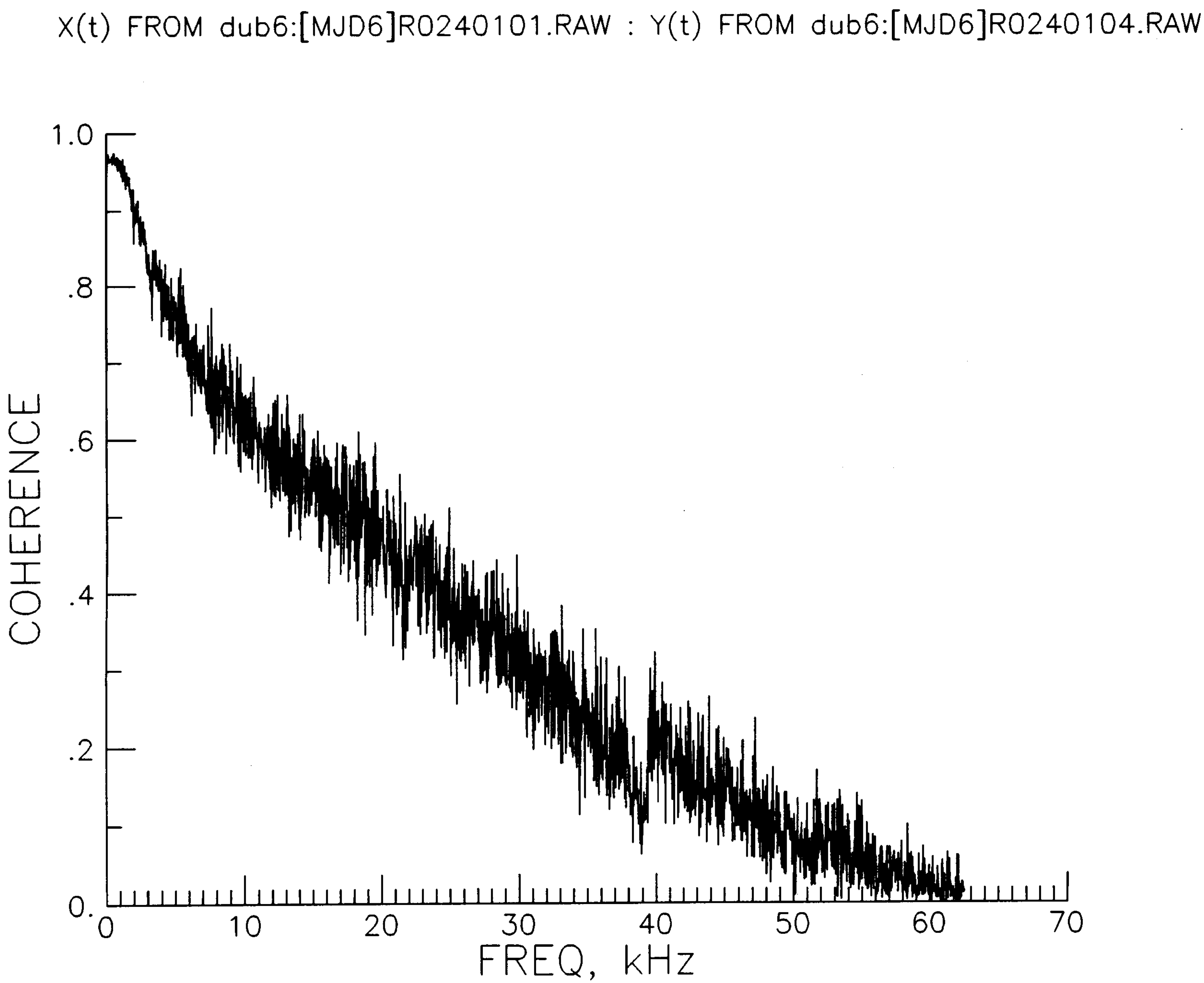

Figure 8.- Coherence.

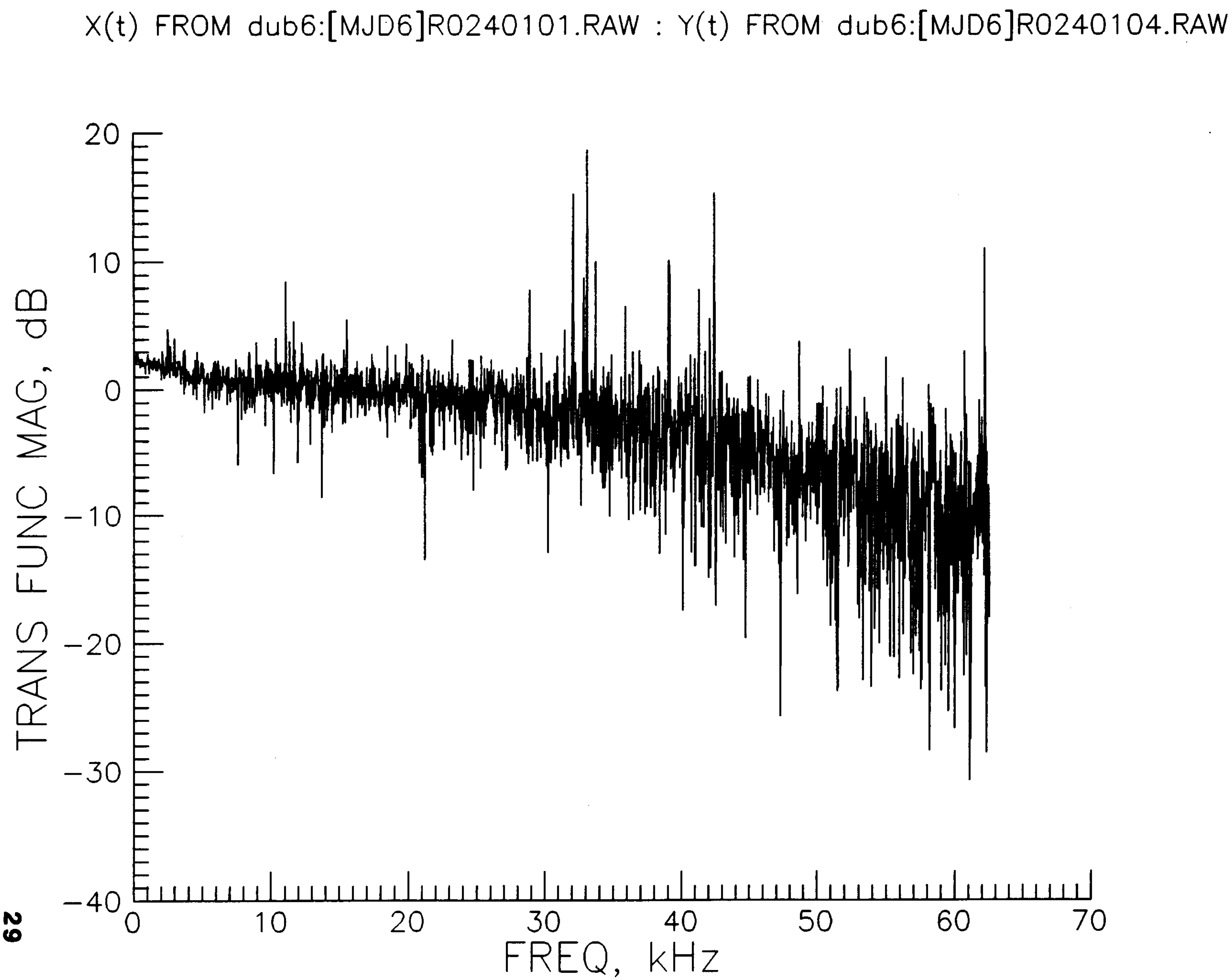

Figure 9.– Transfer function. (a) Magnitude.

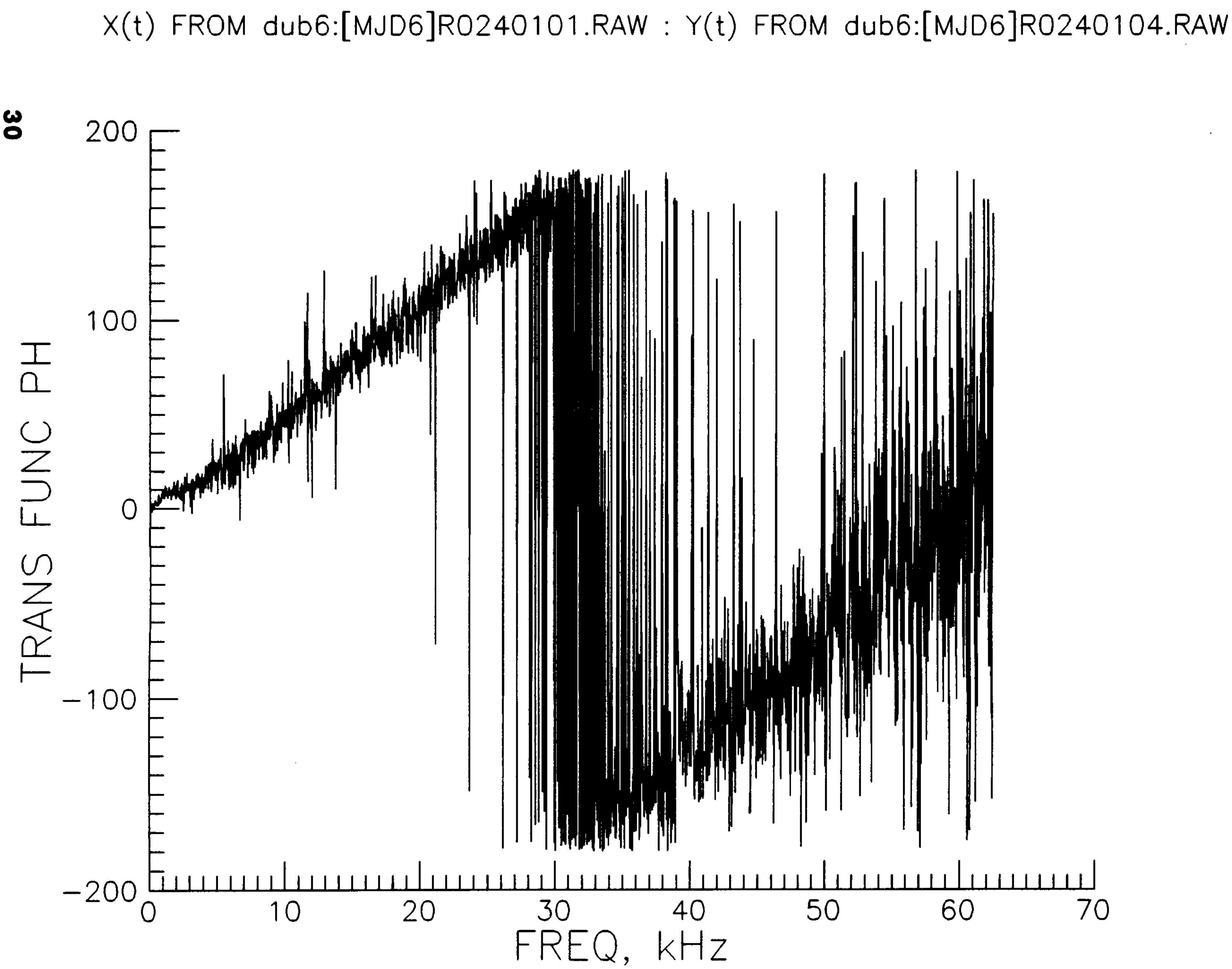

Figure 9.- (b) Phase.

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16. Abstract

The Digital Data System (DDS) was designed to incorporate the analog-to-digital conversion process into the initial data acquisition stage and to store the data in a digital format. This conversion process is done as part of the acquisition process. Consequently, the data are ready to be analyzed as soon as the test is completed. This capability permits the researcher to alter test parameters during the course of the experiment based upon the information acquired in a prior portion of the test. The DDS is currently able to simultaneously acquire up to 10 channels of data.

The purpose of this document is four-fold. The first goal is to describe the capabilities of the hardware in sufficient detail to allow the reader to determine whether the DDS is the optimum system for a particular experiment. The second is to present some of the more significant software which has been developed to provide analyses within a short time of the completion of the data acquisition. The third goal is to provide the reader with sample runs of the major software routines to demonstrate their convenience and simple usage. Finally, a portion of this document is used to describe software which uses an 'FFT-box' to provide a means of comparison against which the DDS can be checked.

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